RF-SYSTEM FOR THE RIBF SUPERCONDUCTING RING CYCLOTRON

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Abstract

The main components of the rf-system for the superconducting ring cyclotron (SRC) at RIBF, RIKEN are described and the commissioning in switching on the resonators is briefly reported. After the installation of the rf-system, a high-power test was performed at a frequency of 36.5 MHz to achieve our first goal of Uranium acceleration with an energy of 345 MeV/u. As soon as the rf-system became ready in December, 2006, the beam commissioning of the SRC started. Finally, an acceleration voltage of 2 MV/turn has been achieved and we succeeded the uranium beam acceleration with a energy of 345 MeV/u.

INTRODUCTION

In RIKEN RIB-factory an accelerator complex which consists of IRC and SRC have been designed and built to accelerate ion beams up to 400 MeV/u. The rf-system has a wide frequency range of 18 $\sim$ 42 MHz required for the acceleration of both light and heavy ions. One of the main issues of the RIKEN RIB-factory is a radio-isotope production by a fission fragment method utilizing Uranium beams. The SRC accelerates $^{238}U^{86+}$ up to 345 MeV/u with a rf frequency of 36.5 MHz.

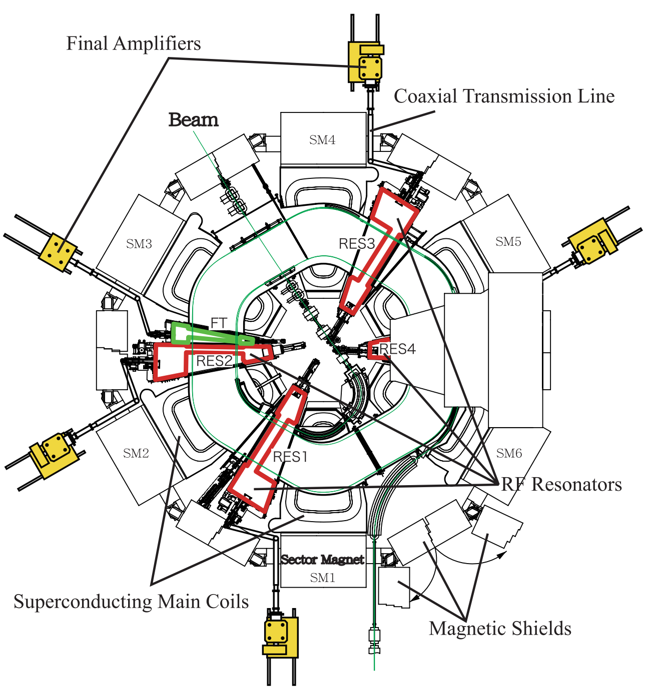

Figure 1: Schematic of SRC showing the arrangement of superconducting magnets, rf resonators (RES1$\sim$4, FT) and power amplifiers.

Table 1: Parameter specification of the rf-system

cavity	main	ft
No. of resonators	4	1
Acceleration gap	single-gap	
Frequency [MHz]	18$\sim$42	72$\sim$126
Harmonic number	6	18 (24)
Amplifier output	150 kW	60 kW
Power tube	RS2042SK /RS2012CJ	RS2058CJ
Driver	Solid state	
	1 kW	3 kW
Stability	$\lvert\Delta V/V\rvert \leq 10^{-4}$ $\lvert\Delta\phi\rvert < 0.1^\circ$	$\lvert\Delta V/V\rvert \leq 10^{-3}$ $\lvert\Delta\phi\rvert < 0.3^\circ$

The SRC consists of six superconducting sector magnets, four acceleration resonators and one flattop resonator. The schematic is shown in Fig.1. The 6 pairs of superconducting main coils generate a magnetic field with a strength of 3.8 T and a K-value of 2600 MeV has been realized. Due to the strong magnetic field an acceleration voltage is required to be as high as possible to obtain a turn separation between beam orbits. Four single-gap resonators (RES1$\sim$4) were installed and their maximum voltage is set to be 600 kV/gap at the high end of the frequency range. A third/fourth-harmonic resonator (FT) enables a flat-top acceleration. A flat-top acceleration is helpful to reduce the energy spread, i.e. beam size in radial direction. Each resonators are equipped with rf power amplifiers which are located at the outside of the magnetic shield. The voltage and phase are accurately controlled by low level circuits to be $\Delta V/V \leq \pm 10^{-4}$ and $\Delta\phi \leq \pm 0.1^\circ$.

COMPONENTS OF THE RF SYSTEM

Resonators

The main resonators[1] for acceleration are single-gap type and work with a sextuple frequency of the beam revolution frequency (H=6). The resonant frequency of the resonator varies from 18$\sim$42 MHz by symmetrical adjustment of two large capacitor-panels. The Q-value and parallel shunt impedance measured by a low power test are

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Table 2: Parameter specification of the resonators at the frequency of 36.5/109.5 MHz

cavity	main	ft
Q_{unloaded}	28000	28000
Rs [MΩ]	1.5	1.6
Max. gap voltage	500 kV	350 kV
Wall loss	80 kW	40 kW
Max. current density	80 A/cm	40 A/cm

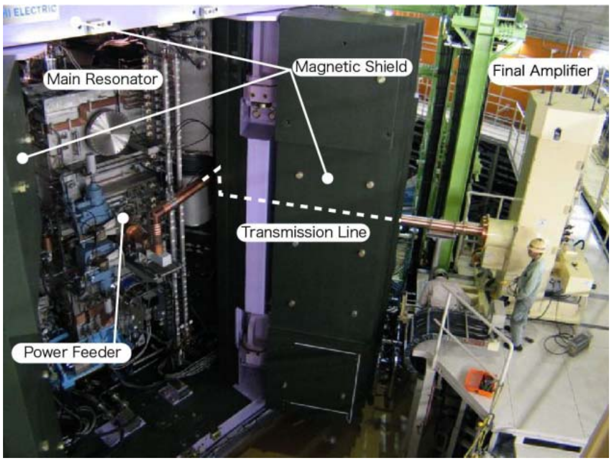

Figure 2: Photograph of the SRC rf-system.

70∼80 % of the ideal values estimated by the computer code MAFIA[2] for the whole frequency range. The rf characteristics at 36.5/109.5 MHz of the resonators are summarized in Table 2.

The third and fourth harmonic of the acceleration frequency is employed for flat-top acceleration for the acceleration frequency of 24∼42 MHz and 18∼24 MHz, respectively. The flat-top resonator, which is also single-gap type, has a pair of sliding short plate for a frequency tuning.

A servo control to tune the resonant frequency is made by moving a pair of block tuners. Rf power is fed by an inductive loop coupler whose coupling is variable by sliding its position.

Cooling of the resonator surface is designed so that maximum temperature is about 80 °C.

Amplifiers

The four main power amplifiers are based on a tetrode SIEMENS RS2042SK coupled with a tetrode RS2012CJ with a grounded-grid circuit. The amplifiers are basically same as those for RIKEN Ring Cyclotorn (RRC)[3]. The main amplifier provides a rf power of 150 kW to the acceleration resonator. A 60 kW power amplifier utilizing a power tube RS2058CJ for a flat-top resonator.

The amplifiers are situated just outside the magnetic shield of SRC, where the stray magnetic field of the superconducting sector magnets is about 100 Gauss in vertical direction. Before connecting to the resonators, a high

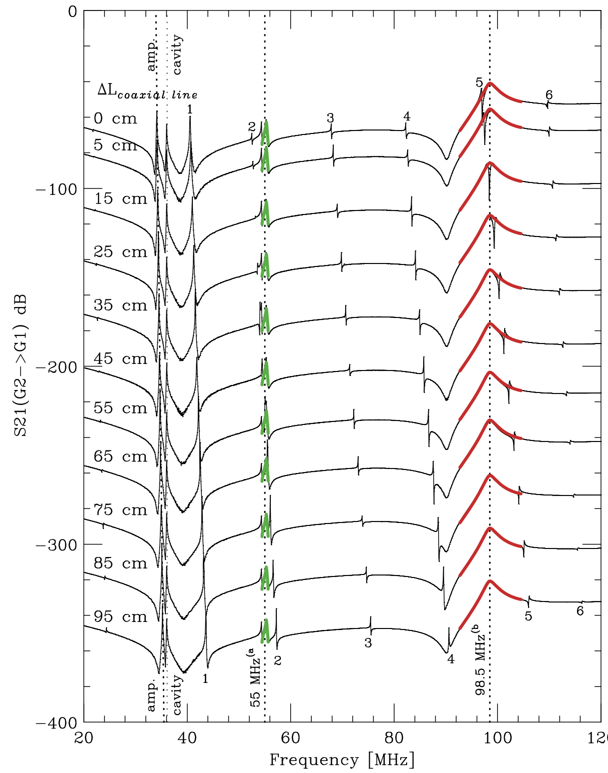

Figure 3: Resonance modes of the rf-system. The resonator and amplifier are tuned to the frequency of 36.5 MHz. The resonances labeled with numbers are HOMs of the transmission line. a) The green peak is a HOM of input circuit. b) The red peak is a resonance between G1- and G2-electrodes.

power test in a stray field was made with a maximum power output. The power was generated quite stably and no change of plate loss was observed.

Transmission lines

Output port of the amplifiers are connected to the resonators with a 50 Ω coaxial line of WX152D for main resonators and WX120D for a flat-top resonator and the resonators are coupled with the coaxial line by inductive couplers. The couplers are tunable to match the impedance of resonator to 50 Ω.

The coaxial-transmission line is equipped with a sliding-system (variable length) and the amplifier is placed on a movable platform so that the length of the transmission-line varies from 7 to 8 m. This is crucial to avoid the HOMs of the transmission line couple with HOMs of the amplifier and the resonator at the whole range of operational frequency. Fig. 3 shows the HOMs of the main rf-system. The resonator and the amplifier were tuned for 36.5 MHz. S-parameter (S_{21}) between ports for power supply of control(G1) and screen(G2) was measured by a network analyzer(Agilent Technology E5061A)'. From our experiences with the amplifiers for RRC, it is known there are two critical modes. One is the resonance of the input stubs at

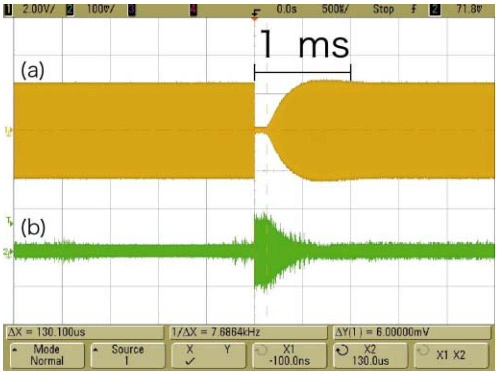

Figure 4: Instant recovery of gap voltage. a):signal from a resonator pickup loop. b):reflection signal of a directional coupler attached to the transmission line.

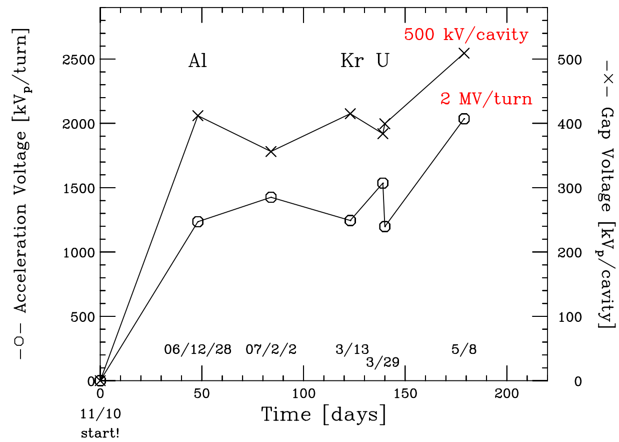

Figure 5: Improvement of the acceleration voltage.

55 MHz and the other is the resonance between G1 and G2 electrodes of the power tube which appears at 98.5 MHz. The position of 0 cm has been selected for 36.5 MHz operation.

Operation

In operation the rf gap voltage and phase are monitored with a signal from loop pick up and stabilized by rf control devices, level controller and a phase controller(Thamway A081-1067B). The level controller is used with pulse/cw mode in which the rf signal output turns into pulse mode as soon as the gap voltage breaks down and turns to cw mode again when the voltage comes back. Fig. 4 shows that a recovery of the gap voltage was made within 1 ms.

COMMISSIONING

Installation of the resonators, power amplifiers and low-level controls to the SRC was made since July 2006 and was finished in October 2006. After the installation, a power-test started on 13th November.

In the beginning, due to the multipacting of the resonator, the rf power was fed with a pulse-mode for conditioning of the resonator observing the envelopes of the pulsed signals from the resonator pickup, the forward and backward directional couplers on the transmission line and the vacuum pressure. The width of the pulse was typically a few hundred micro seconds and the duty was less than 1 %. It took only a few days per one resonator for the initial conditioning with a pulse-mode operation until the cw-mode became available. In the conditioning process the peak power was decreased step by step from one hundred kW to a few tens kW then the mode turned to cw. The vacuum pressure reached 1×10^{-5} Pa.

Initial difficulty we encountered is that it was hard to overcome the multipacting with a magnetic field of the superconducting sector magnets. The strength of the stray field is a 200∼400 gauss in valley region. It took one week to get cw-mode. On 27th November, the first resonator became operational in cw mode and at last the rf-system has successfully accelerated aluminum beams to 345 MeV/u on 28th December, 2006 as reported in [4]. Improvement of the gap voltage was made in the first quarter of this year by the conditioning of the resonator and tuning of amplifier. The careful conditioning of the resonator was made with a pulse mode operation increasing the magnetic field step by step for a few weeks. Finally the acceleration voltage of 2 MV/turn at 36.5 MHz has been achieved and the performance of the rf-system was verified.

OUTLOOK

Tuning of phase and voltage control is in under way and it is expected to satisfy the requirement. Performance of the flat-top acceleration is not verified yet. It is needed to improve the beam diagnostics of SRC to optimize the phase and voltage of the flat-top resonator. An acceleration test with Uranium is scheduled in the end of October. In near future, 500 MeV polarized-deuteron acceleration at a frequency of 27 MHz is going to be performed.

ACKNOWLEDGMENT

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